CLAIMS

1. A method of milling grooves in a work-piece comprising:

providing an abrasive fluidjet device mounted on a manipulator and emitting an abrasive fluidjet from the device; and

traversing the abrasive fluidjet across the work-piece to form a groove in the work-piece, including executing a plurality of passes with the abrasive fluidjet being oriented at a different impingement angle for at least two of the passes.

2. The method of claim 1 wherein the different angles include a negative or positive lateral angle.

3. The method of claim 2 wherein the negative or positive lateral angle is between about 2 and about 5 degrees.

4. The method of claim 1 wherein the different angles include negative or positive lateral angles of varying degrees as measured from an intersecting vertical line in a lateral plane.

5. The method of claim 1 wherein at least one pass is executed with the abrasive fluidjet oriented at a leading angle.

6. The method of claim 5 wherein the leading angle is about 2 to about 20 degrees.

7. The method of claim 1 wherein at least one pass is executed with the fluidjet oriented at a trailing angle.

8. The method of claim 1 wherein an abrasive is mixed with a fluidjet within a mixing tube of the abrasive fluidjet device to produce the abrasive fluidjet, and wherein the mixing tube has a length up to 200 times an average diameter of an axial interior channel of the mixing tube.

9. The method of claim 1 wherein an abrasive is mixed with a fluidjet within a mixing tube of the abrasive fluidjet device to produce the abrasive fluidjet, and wherein the mixing tube has a length of about 4 inches.

10. The method of claim 1 wherein an abrasive is mixed with a fluidjet within a mixing tube of the abrasive fluidjet device to produce the abrasive fluidjet, and wherein the mixing tube has an axial interior channel with a diameter of about 0.020 to about 0.100 inches.

11. The method of claim 10 further comprising passing fluid from a high pressure fluid source through an orifice to generate the fluidjet and where in the orifice diameter is about 0.005 to about 0.025 inches.

12. A method of milling grooves in a work-piece using an abrasive fluidjet comprising:

adjusting a lateral angle of the abrasive fluidjet to a negative lateral angle and executing at least one pass across the work-piece;

adjusting the lateral angle of the abrasive fluidjet to a positive lateral angle and executing at least one pass across the work-piece; and

adjusting the longitudinal angle of the abrasive fluidjet to at least one of a leading and trailing angle and executing at least one pass across the work-piece.

13. The method of claim 12 wherein the negative lateral angle and the positive lateral angel are about 2 to about 3 degrees.

14. The method of claim 12 wherein the at least one of a leading and trailing angle is about 2 degrees to about 20 degrees.

15. The method of claim 12 further comprising adjusting the strength of the abrasive fluidjet for at least one of the plurality of passes.

16. The method of claim 12 further comprising adjusting a stand-off distance of an abrasive fluidjet device from which the abrasive fluidjet is emitted for at least one of the plurality of passes.

17. The method of claim 12 further comprising adjusting the speed of at least one of the passes between passes or during the pass.

18. A method of milling grooves in a work-piece by traversing an abrasive fluidjet across the work-piece, the method comprising:

executing a plurality of passes across the work-piece using the abrasive fluidjet with the fluidjet oriented at different angles for at least two of the passes;

changing a standoff distance for an abrasive fluidjet device from which the abrasive fluidjet is emitted for at least one of the plurality of passes; and

moving the abrasive fluidjet device laterally to change an impingement line of the abrasive fluidjet.

19. The method of claim 18 further comprising executing at least two of the passes at different traverse speeds.

20. The method of claim 18 wherein the abrasive fluidjet device is moved laterally without changing a lateral angle of the abrasive fluidjet.

21. The method of claim 18 wherein at least one the plurality of passes is executed with the abrasive fluidjet directed along a curved impingement line.

22. The method of claim 18 further comprising adjusting a degree of a lateral angle to execute at least two of the plurality of passes with lateral angles at different degrees.

23. The method of claim 18 wherein the different angles comprise at least one of a negative lateral angle and positive lateral angel at about 2 to about 3 degrees.

24. The method of claim 18 wherein the different angles comprise at least one of a leading angle and trailing angle at about 2 to about 20 degrees.

25. The method of claim 18 wherein the different angles comprise at least one of a leading and trailing angle at about 15 to about 20 degrees.

26. The method of claim 18 wherein changing the standoff distance comprises adjusting the standoff distance to about 0.05 to about 0.15 inches between a nozzle of the abrasive fluidjet device and the a surface of the work-piece.

27. The method of claim 18 wherein changing the standoff distance comprises adjusting the standoff distance to about 0.1 to about 0.5 inches between a nozzle of the abrasive fluidjet device and the a surface of the work-piece.

28. The method of claim 18 wherein at least one of the plurality of passes is executed over the work-piece at a speed of about 100 inches/minute to about 600 inches/minute.

29. The method of claim 18 wherein at least one of the plurality of passes is executed over the work-piece at a speed of about 150 inches/minute.

30. A method for milling grooves in a work-piece with an abrasive fluidjet device comprising:

carrying the abrasive fluidjet device across the work-piece using a manipulator configured to adjust lateral angles and longitudinal angles of an abrasive fluidjet emitted from the abrasive fluidjet device, the manipulator being configured to move the abrasive fluidjet device laterally, longitudinally, and vertically across the work-piece; and

executing a plurality of passes across the work-piece with the abrasive fluidjet with at least two of the passes being executed with different lateral angles and at least one of the plurality of passes being executed with a leading or trailing longitudinal angle.

31. The method of claim 30 further comprising executing at least one pass across the work-piece with the axis of the abrasive fluidjet being aligned vertically to remove material from a central portion of a bottom surface of a desired groove.

32. The method of claim 30 further comprising executing at least one pass across the work-piece with the abrasive fluidjet being aligned vertically to remove material from a wall portion of a desired groove.

33. The method of claim 30 further comprising executing at least one pass across the work-piece with a negative or positive lateral angle imparted to the abrasive fluidjet and with the abrasive fluidjet directed at a wall portion of a desired groove.

34. The method of claim 33 wherein the degree of the negative or positive lateral angle is sufficient to form an undercut wall in a groove.

35. The method of claim 33 wherein the degree of the negative or positive lateral angle is sufficient to form a straight transverse wall in a groove.

36. The method of claim 30 further comprising executing at least one pass across the work-piece with the abrasive fluidjet directed along an impingement line at a central portion of a bottom surface of a groove with the fluidjet strength increased in comparison with at least one of the other of the plurality of passes.

37. The method of claim 30 further comprising executing at least one pass across the work-piece with the abrasive fluidjet imparted with one of a leading angle and trailing angle.

38. The method of claim 37 wherein the leading or trailing angle is between about 2 and about 20 degrees.

39. The method of claim 37 wherein the leading or trailing angle is about 19 degrees.

40. The method of claim 30 wherein at least one of the plurality of passes is executed with the abrasive fluidjet oriented with a positive or negative lateral angle and a lead or trailing angle.

41. The method of claim 30 wherein the abrasive fluidjet is oriented with a positive lateral angle and a leading longitudinal angle.

42. The method of claim 30 wherein the abrasive fluidjet is oriented with a negative lateral angle and a trailing longitudinal angle.

43. The method of claim 30 wherein the plurality of passes across the work-piece comprise at least one pass with a positive lateral angle with a corresponding return pass being executed with a different lateral angle.

44. A method of milling a groove in a work-piece, comprising:

providing a plurality of abrasive fluidjet devices mounted within an assembly with the abrasive fluidjet devices oriented to emit corresponding abrasive fluidjets at a plurality of angles including a positive or negative lateral angle; and

executing at least one milling pass across the work-piece with a plurality of abrasive fluidjets being emitted from the plurality of corresponding abrasive fluidjet devices and simultaneously impinging on the work-piece.

45. The method of claim 44 wherein there are three abrasive fluidjets simultaneously impinging on the work-piece during the at least one milling pass.

46. The method of claim 44 wherein there are at least two abrasive fluidjets simultaneously impinging on the work-piece during the at least one milling pass and wherein one of the abrasive fluidjets is oriented with a positive lateral angle and another of the abrasive fluidjets is oriented at zero lateral angle.

47. The method of claim 44 wherein there are at least two abrasive fluidjets simultaneously impinging on the work-piece during the at least one milling pass and wherein one of the abrasive fluidjets is oriented with a positive lateral angle and another of the abrasive fluidjets is oriented with a negative lateral angle.

48. The method of claim 44 wherein there are at least three abrasive fluidjets simultaneously impinging on the work-piece during the at least one milling pass and wherein a first abrasive fluidjets is oriented with a positive lateral angle, a second abrasive fluidjet is oriented at zero lateral angle, and a third abrasive fluidjet is oriented with a negative lateral angle.

49. The method of claim 48 wherein the first abrasive fluidjet is also oriented with a leading longitudinal angle and the third abrasive fluidjet is also oriented with a trailing longitudinal angle.

50. The method of claim 48 wherein a standoff distance for each corresponding abrasive fluidjet device for the first and third abrasive fluidjets is about 0.05 inches to about 0.15 inches.

51. The method of claim 48 wherein a standoff distance for the corresponding fluidjet device for the second abrasive fluidjet is about 0.1 to about 0.5 inches.

52. The method of claim 48 wherein the positive and negative lateral angles of the first and third abrasive fluidjets are about 2 degrees to about 3 degrees.

53. The method of claim 48 wherein the first abrasive fluidjet is also oriented with a leading longitudinal angle and the third abrasive fluidjet is also oriented with a trailing longitudinal angle and wherein the leading and trailing longitudinal angles are about 2 degrees to about 20 degrees.

54. The method of claim 48 wherein the first abrasive fluidjet is also oriented with a leading longitudinal angle and the third abrasive fluidjet is also oriented with a trailing longitudinal angle and wherein the leading and trailing longitudinal angles are about 19 degrees.

55. The method of claim 48 wherein a traverse rate for the at least one milling pass is between about 100 inches/minute and about 600 inches/minute.

56. The method of claim 48 wherein a traverse rate for the at least one milling pass is about 150 inches/minute.

57. A method of milling grooves in a work-piece comprising:

traversing a plurality of fluidjet nozzles over a work-piece;

emitting a first fluidjet from at least one of the nozzles to form a groove in the work-piece, the first fluidjet being oriented with both a positive lateral angle and a leading angle; and

emitting a second fluidjet simultaneously with the first fluidjet from at least one of the nozzles to form the groove, the second fluidjet being oriented with both a negative lateral angle and a trailing angle.

58. The method of claim 57 wherein there are at least three fluidjets emitted simultaneously from the fluidjet nozzles to form the groove.

59. The method of claim 57 wherein one of the plurality of fluidjets impinges on the work-piece vertically with zero lateral angle and zero longitudinal angle.

60. A multiple jet apparatus for use in milling grooves in a work-piece, the multiple jet apparatus comprising a plurality of nozzles for emitting a plurality of abrasive fluidjets wherein a first nozzle is oriented with a positive lateral angle and a leading angle, a second nozzle is oriented vertically, and a third nozzle is oriented with a negative lateral angle and a trailing angle.

61. The multiple jet apparatus of claim 60 wherein the second nozzle is disposed between the first and third nozzles.

62. The multiple jet apparatus of claim 60 wherein the length of at least one of the nozzles is up to 200 times greater than an average diameter of an inside channel of the nozzle.

63. The multiple jet apparatus of claim 60 wherein the length of at least one of the nozzles is about 2.0 to about 6.0 inches.

64. The multiple jet apparatus of claim 60 wherein the length of at least one of the nozzles is about 4 inches.

65. The multiple jet apparatus of claim 60 wherein an average diameter of an inside channel of at least one of the nozzles is about 0.020 to about 0.100 inches.

66. A fluidjet mounting assembly comprising:

a base member; and

a plurality of retaining members coupled to the base member for retaining a plurality of fluidjet devices with at least a first retaining member being configured to impart a positive lateral angle and a leading longitudinal angle to a nozzle of a fluidjet device retained by the first retaining member and with at least a second retaining member being configured to impart a negative lateral angle and a trailing longitudinal angle to a nozzle of a fluidjet device retained by the second retaining member.

67. The mounting assembly of claim 66 further comprising a third retaining member configured to orient a nozzle of a fluidjet device vertically with zero lateral and zero longitudinal angle.

68. The mounting assembly of claim 66 wherein when fluidjet devices are disposed within each of the retaining members, a discharge end of each nozzle of the fluidjet devices is disposed in close proximity to another discharge end of another fluidjet device.

69. The mounting assembly of claim 66 wherein when fluidjet devices are disposed within each of the retaining members, a discharge end of each nozzle of the fluidjet devices is disposed within about a diameter's length of a discharge end of another nozzle of

another fluidjet device, wherein the diameter's length is equal to an outside diameter of one of the nozzles.

70. The mounting assembly of claim 66 wherein when fluidjet devices are disposed within each of the retaining members, a discharge end of each nozzle of the fluidjet devices is disposed within a half of a diameter's length of a discharge end of another nozzle of another fluidjet device, wherein the diameter's length is equal to an outside diameter of one of the nozzles.

71. A method of milling grooves in a work-piece comprising:

executing a plurality of milling passes on a surface of the work-piece using an abrasive fluidjet with at least one of the passes executed with a positive or negative lateral angle imparted to the abrasive fluidjet and with at least one of the passes executed with a leading or trailing angle imparted to the abrasive fluidjet; and

rotating the work-piece about an axis thereof in between each milling pass.

72. The method of claim 71 wherein the work-piece includes a conically shaped portion and rotating the work-piece comprises rotating the work-piece about a longitudinal axis of the conically shaped portion.

73. A method of milling grooves in a work-piece comprising directing an abrasive fluidjet at the work-piece with the abrasive fluidjet oriented with a positive or negative lateral angle and a leading or trailing longitudinal angle and simultaneously rotating the work-piece about a longitudinal axis thereof.

74. The method of claim 73 further comprising traversing the abrasive fluidjet along a longitudinal axis of the work-piece while rotating the work-piece about the longitudinal axis thereof, whereby a helically shaped groove is formed on a surface of the work-piece.

75. The method of claim 73 wherein the work-piece includes a conically shaped portion and rotating the work-piece comprises rotating the work-piece about a longitudinal axis of the conically shaped portion.